THE RELATIVE AGE OF ICE SCOURS USING CROSS-CUTTING RELATIONSHIPS

Christopher M.T. Woodworth-Lynas

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C-CORE

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ABSTRACT

Iceberg scour marks are straight or curvilinear troughs on the seabed which have been formed by grounding iceberg keels as they are carried forward by ocean currents. A new method for dating the relative ages of ice scour utilizes cross-cutting relationships. The method allows delineation of relative age groups and identification of oldest and youngest end member scours from sidescan sonar mosaics. Selective coring of two or more end member scour troughs from a scour population in which undisturbed sediments have accumulated and use of conventional absolute age dating techniques should establish the age of the population from which a scouring rate can be extrapolated. A decrease in scour width with decreasing scour age shows positive correlation and has been used to show a possible net decrease in iceberg size with time.

ACKNOWLEDGEMENTS

Special thanks go to Dr. C.F.M. Lewis of the Atlantic Geoscience Centre for his comments and interest and for the use in this report of sidescan data collected during two research cruises of the Bedford Institute of Oceanography vessel **CSS HUDSON**. The author gratefully acknowledges critical reviews of the manuscript by Dr. C.F.M. Lewis, Dr. R.J. Rogerson, Dr. C.P.G. Pereira, J.V. Barrie and W. Collins. Special thanks go to Alvin Simms who greatly helped in the statistical analysis.

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INTRODUCTION

When the keel of an iceberg or a sea ice pressure ridge (pendant ice) strikes the seafloor it either becomes grounded and ceases to move or, if driven with sufficient force, the keel penetrates the seafloor sediment and excavates a trough that is commonly referred to as a scour (Pelletier and Shearer, 1972). Scours are straight or curvilinear troughs, commonly 30m in width and over 3 km long. They characteristically have raised margins or berms, and may be up to 6.5 m deep (Harris and Jollymore, 1974). Grounding of icebergs and pendant ice in shallow seas is a well-established phenomenon and has been reported frequently from the eastern Canadian Continental Shelves during the last few decades (Pelletier and Shearer, 1972; Smith, 1977; Allen, 1972; Løken, 1973; Barrie et al., 1981). Much work has been directed at understanding the distribution of scour marks (Pelletier and Shearer, 1972; Belderson and Wilson, 1973 a & b; Lewis, 1978) and the mechanics of scouring (Chari, 1978; 1980; Chari and Peters 1981).

The prediction of iceberg movement and iceberg flux along the Canadian east coast has also been attempted (Allen, 1972; Russell, 1973; Dempster, 1974; Riggs et al., 1980; Robe et al., 1979; El-Tahan, 1980; Sodhi and El-Tahan, 1980; Ebbesmeyer et al., 1980; Ball et al., 1981; Barrie et al., 1981). Such studies have proved useful in determining the hazards posed by icebergs to offshore drilling ships and platforms located in Canadian Arctic and sub-Arctic regions. However, these approaches have not dealt with the problem of iceberg impacts on the seafloor. Such impacts are

important to offshore operators who need to predict the depth and frequency of scouring by icebergs in areas where the placement of seabed facilities such as well heads or pipelines are planned. The fundamental problem in ice scour research has been in developing a successful technique for dating the age of scouring in a given area. For instance, some scours may be relict or late glacial, formed in shallow seas many thousands of years ago, while others may be contemporary. For those which are recent in age scouring flux rates and a predictive scour-frequency model need to be defined. Several methods for dating scours and scour populations and for predicting future scour occurrences are summarized and discussed.

METHODS FOR DATING SCOUR POPULATIONS

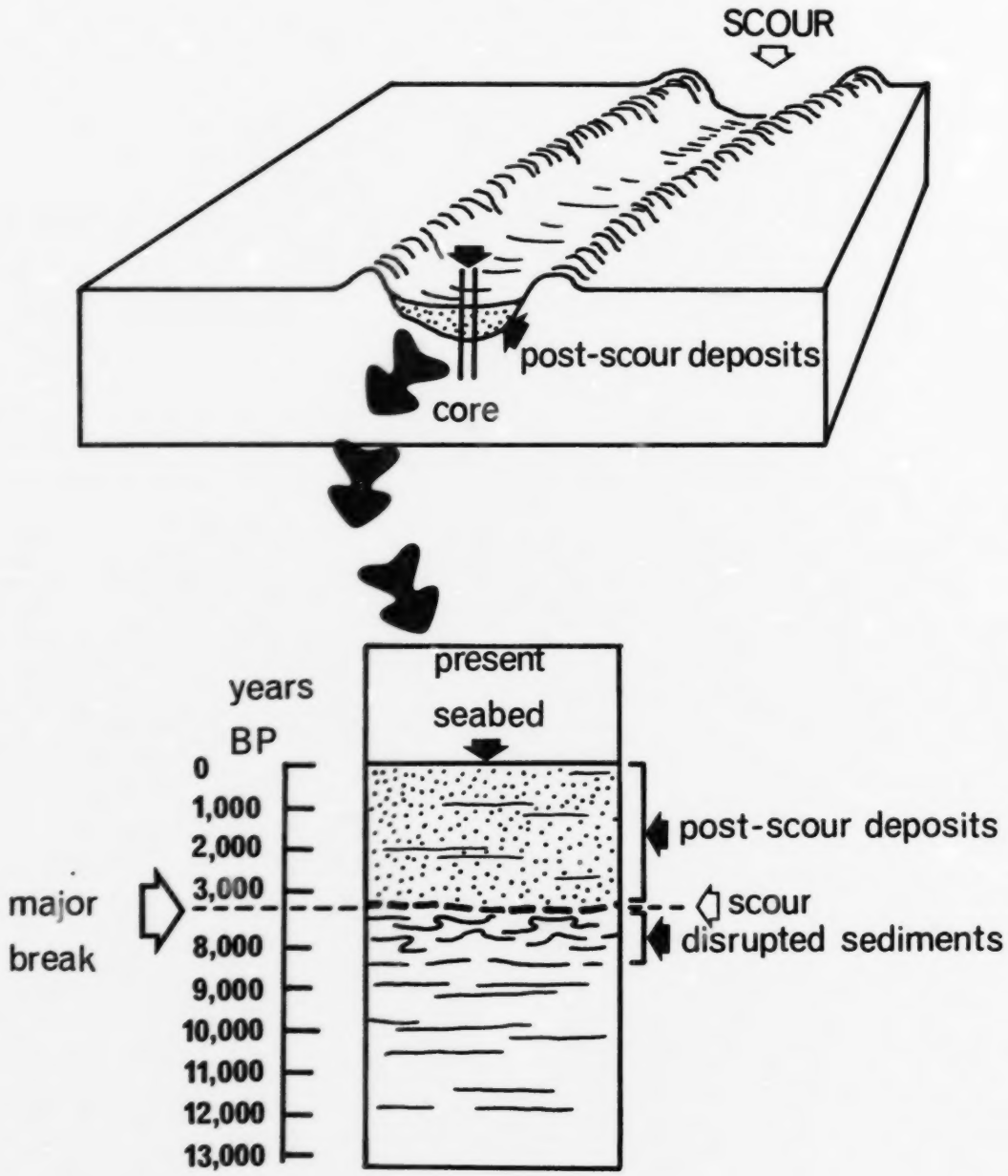
Scour Obliteration

After formation, a scour may be partly or completely obliterated as it is filled in with sediment carried by bottom currents or falling from suspension. The amount of sediment infilling has been used to estimate the absolute age of ice scours in the Beaufort Sea, (Hunting, 1971; Pelletier and Shearer, 1972; Lewis, 1977; Barnes and Reimnitz, 1979; Pilkington and Marcellus, 1981). Significant results have not been obtained, however, since rates of sediment infilling in the region are not sufficiently known.

Direct Dating of Sediments in Scours

Direct dating involves the retrieval of datable material from sediments in a scour trough. Absolute dates of biogenic material from the scoured sediment and infilling sediment should bracket the absolute age of an individual scour (Fig. 1). Absolute dating techniques include the use of C^{14}, Pb^{210}, electron spin resonance and shell growth. However, in order to date a scour population a large number of core samples are required from the centres of many scour troughs. The logistics involved in retrieving cores from scours are difficult, expensive and subject to high potential failure if insufficient dating material is obtained. Furthermore, this approach is most suitable for areas where sediment has settled from suspension and has accumulated without subsequent disturbance of the seabed. Scoured areas where

Figure 1 - Method for dating absolute age of a scour. The age of the original scour surface can be given a minimum value (in this case 3,000 B.P.) by dating the base of the infilling sediment using conventional techniques.


SCOUR
post-scour deposits
core
present
seabed
years
BP
0
1,000
2,000
3,000
8,000
9,000
10,000
11,000
12,000
13,000
major
break
post-scour deposits
scour
disrupted sediments

non-deposition, erosion and reworking by ocean currents have occurred are unsuitable because reworked biogenic material in the infilling sediment in scour troughs may give misleading absolute ages.

Repetitive Mapping

This method has been used successfully in the Beaufort Sea (Reimnitz and Barnes, 1974; Reimnitz et al., 1977; Lewis, 1977; Barnes et al., 1978) and off Labrador (Lewis and Barrie, 1980), and involves resurveying (usually on an annual basis) a specific area of the scoured seabed using sidescan mosaic techniques. By comparing the yearly mosaics, newly-formed scours can be identified and counted, and a return rate can be computed (Lewis, 1977; Pilkington and Marcellus, 1981).

Dating of Old Scour Populations from Quaternary Evidence

Ancient scour populations may be bracketed in time using:

a) the position of submerged strand lines (the ages of which are known) with respect to scour populations (King, 1976),

b) the location and duration of calving glacier margins which produced icebergs in areas that are now free of icebergs (King, 1976),

c) the location of areas that are known to have been protected from scouring icebergs by ice tongues and ice sheets whose age and duration are known (Fillon and Harmes, 1982).

Dredge (1982) has used the existence of relict scours in northern Manitoba to identify a paleostrandline during the late stage of occupation of the area by glacial Lake Agassiz.

Scour Degradation

Josenhans and Barrie (1982) described the relative ages of iceberg scours on Makkovik and Harrison Banks on the Labrador Shelf by direct observation of scour morphology from the submersible **PISCES IV.** They differentiated older from younger scours using three criteria:

a) the degree of winnowing of fine sediments from the scour berms,

b) relief of the scour berms and

c) the extent of biogenic colonization on ice rafted boulders in the scour trough. However, recently rafted boulders in ancient scour troughs will give misleading information.

Scour Depth Analysis

Scour depth has been shown to vary with water depth in a positive exponential form; the scours are generally more deeply incised in deeper water (Lewis, 1977; Wahlgren, 1979). Barrie (1980) used this parameter to distinguish between a relict scour population in water depths greater than 180m and a more recent population less than this depth on Saglek Bank on the Labrador Shelf.

Ice Keel Statistics

This method calculates the probability of return frequency for an ice keel of a certain draft passing over a point on the seabed in a given time period using both collected and estimated data for ice keels and observed scour penetration depths on the seafloor. Keel draft can be obtained from laser profilometers, sonar profilers, coring and profiling data from upward-looking sonars either attached to submersibles or on the seabed (Weeks et al., 1971; Pilkington and Marcellus, 1981).

Cross-cutting Relationships

It is possible to determine the relative age of scours using the geological principle of cross-cutting relationships. Essentially, the oldest scours are cut by younger scours but do not cut any others, and the youngest scours are those that cut older scours but which are not cut by others. Scours of intermediate age will cut older scours and will also be cut by younger scours.

PREVIOUS WORK

Weber (1958) was the first to note cross-cutting relationships of scours in Great Slave Lake. Here, scours which formed near the shoreline during the winter by grounding wind-blown ice, cut across the tops of relict glacial furrows produced at the bed of a glacier. The principle of cross-cutting with respect to scours made by pendant ice in the Beaufort Sea was first mentioned by Pelletier and Shearer (1972). They observed "numerous occurrences of cross-cutting relationships ... indicating that several periods of ice-scouring have occurred". Berkson and Clay (1973) in their work on late glacial iceberg scours in western Lake Superior also noted cross-cutting relationships of scours. They constructed a map from sidescan records showing scour distribution and scour cross-cuttings. However they did not use this as a method for obtaining relative scour ages. Hnatiuk and Brown (1977) working in the Beaufort Sea correlated scour cross-cuttings with scour azimuth but found no significant relationship. Dredge (1982) observed the cross-cutting phenomenon in relict scours developed in sediments of glacial Lake Agassiz but noted only that cross-cutting caused distortion of scour shapes.

STUDY AREAS

In two severely scoured areas of Saglek Bank on the Labrador shelf (Saglek East and Saglek West) and in one area of the southeastern Baffin Island shelf (Hekja North) (Fig. 2) numerous cross-cutting scours were observed from sidescan mosaics. Maps were constructed from the sidescan mosaics of the three areas showing the cross-cutting relationships of the scours (Figs. 3, 4 and 5).

Examination of the scours showed that morphological criteria were needed in order to interpret the cross-cutting relationships where they appear to be ambiguous (Fig. 6). When it was not possible to determine the relative age of two cross-cutting scours the relationship on the map was left as unknown. These morphological criteria are probably applicable to other densely scoured terrains (e.g. Beaufort Sea and other parts of the Baffin Island and Labrador shelf). However, they cannot be applied to areas such as the Grand Banks because of the paucity of observed scours and cross-cuttings and differences in the geotechnical characteristics of the scoured seabed.

For the Saglek Bank and Hekja North areas, cross-cutting relationships for all the scours were listed and a computer program was written to facilitate the classification of scours into relative age groups.

Figure 2 - Location of map of study areas

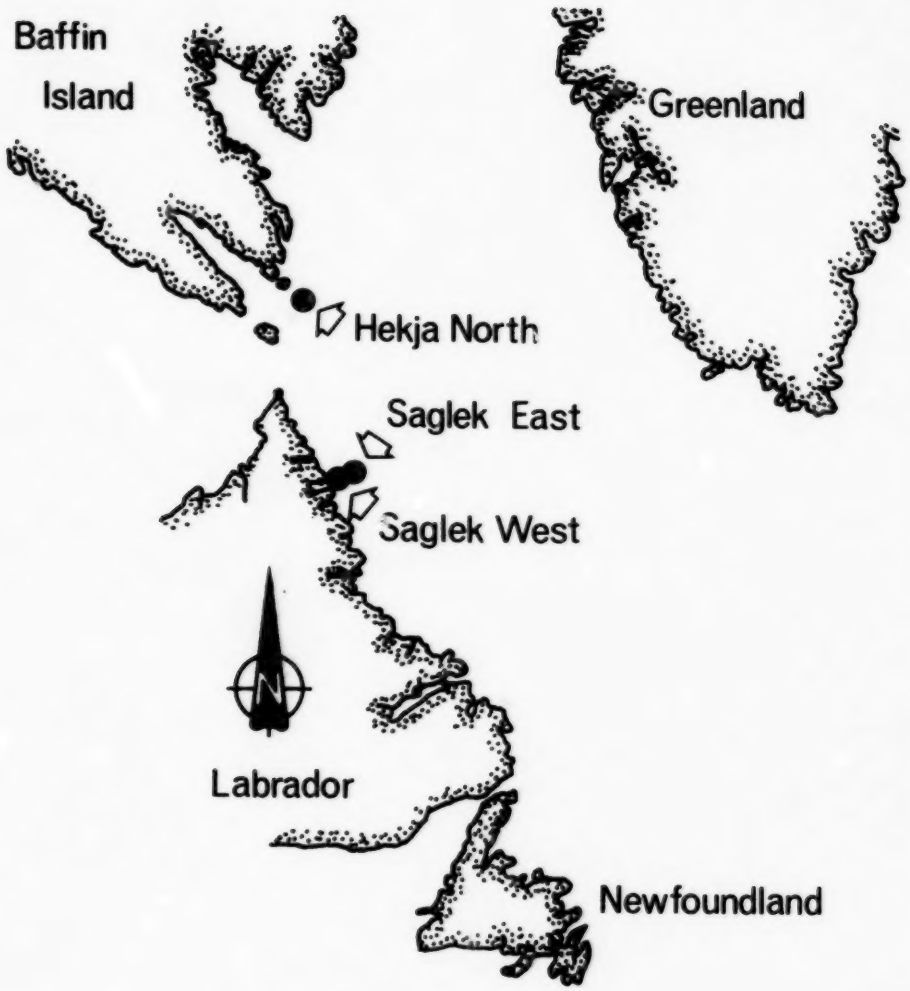

Baffin
Island
Greenland
Hekja North
Saglek East
Saglek West
N
Labrador
Newfoundland

Figure 3a - Saglek East mosaic area showing iceberg scours. The black outline shows the area of enlargement in figure 3b.

SIDE SCAN MOSAIC, SAGLEK BANK
CSS HUDSON 79-019

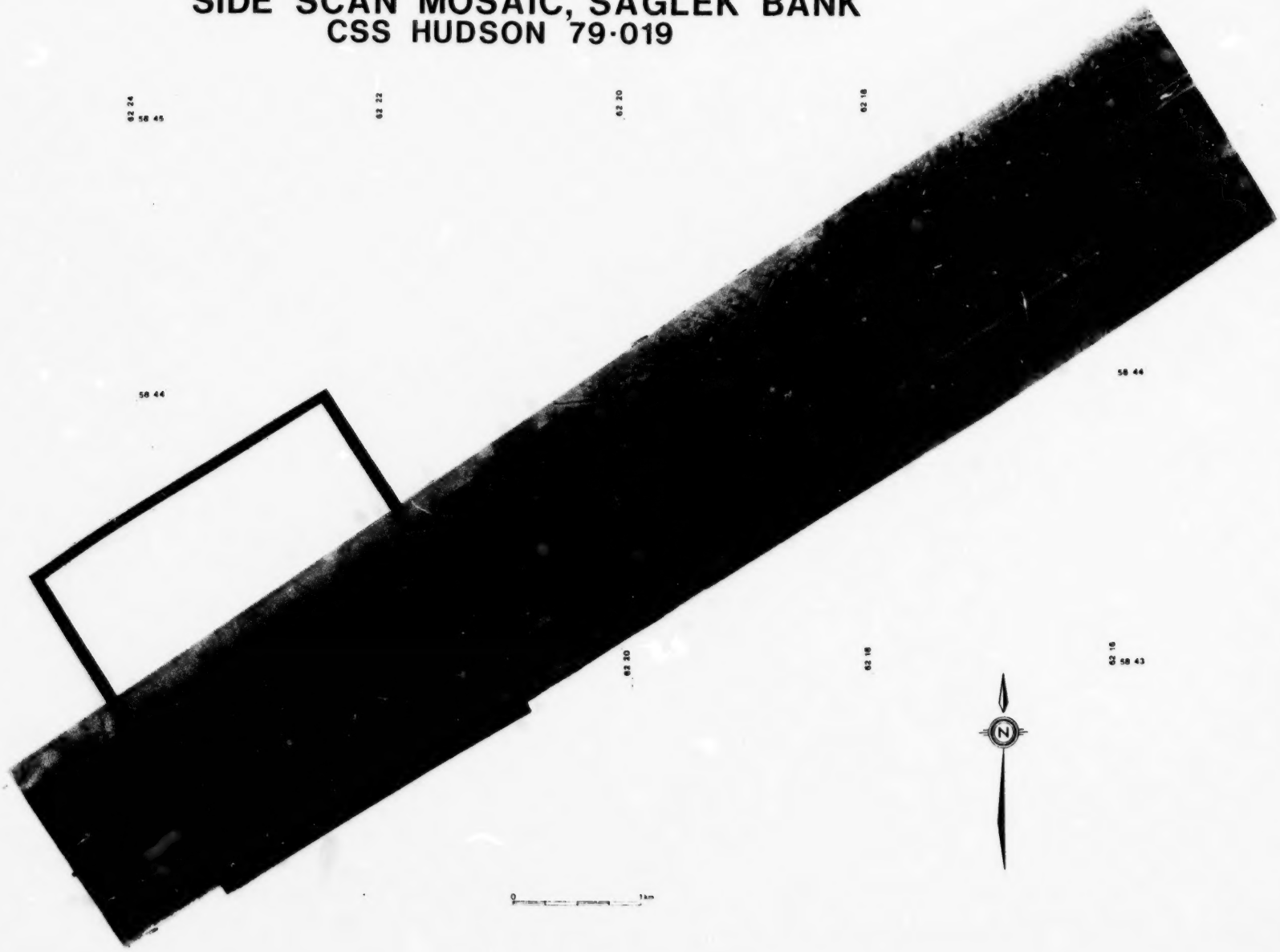


Figure 3b - Portion of Saglek East scour map (see fig. 3a) showing the interpreted cross-cuts.

LEGEND

X cutting scours

Letters refer to scours that should be dated.

62°22' — 58°44'

58°43' — 62°20'

O km 1

Figure 4a - Saglek West mosaic area showing iceberg scours. The black outline shows the area of enlargement in figure 4b.

SIDE SCAN MOSAIC, SAGLEK BANK
CSS HUDSON 79-019

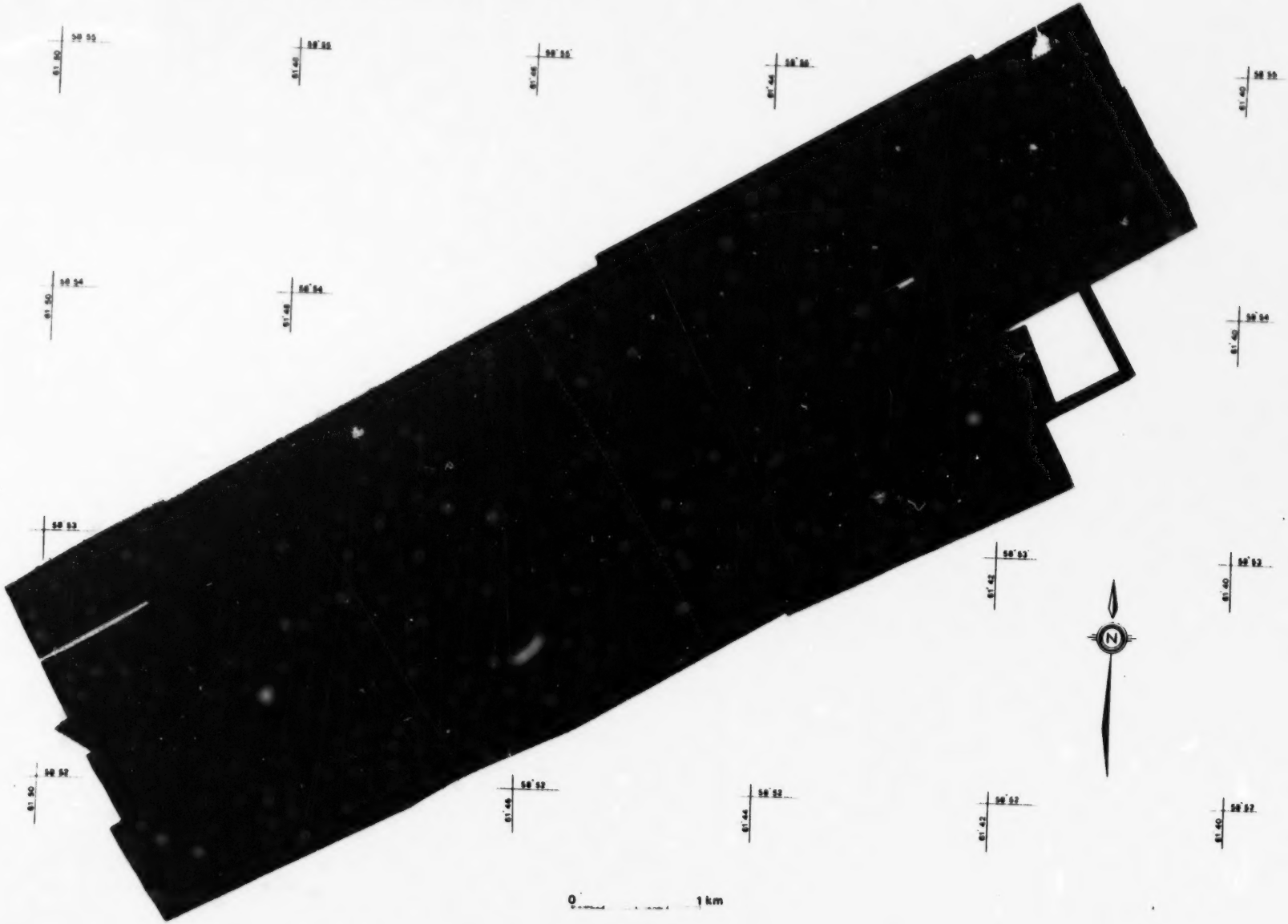


Figure 4b - Portion of Saglek West scour map (see Fig. 4a) showing the interpreted cross-cuts.

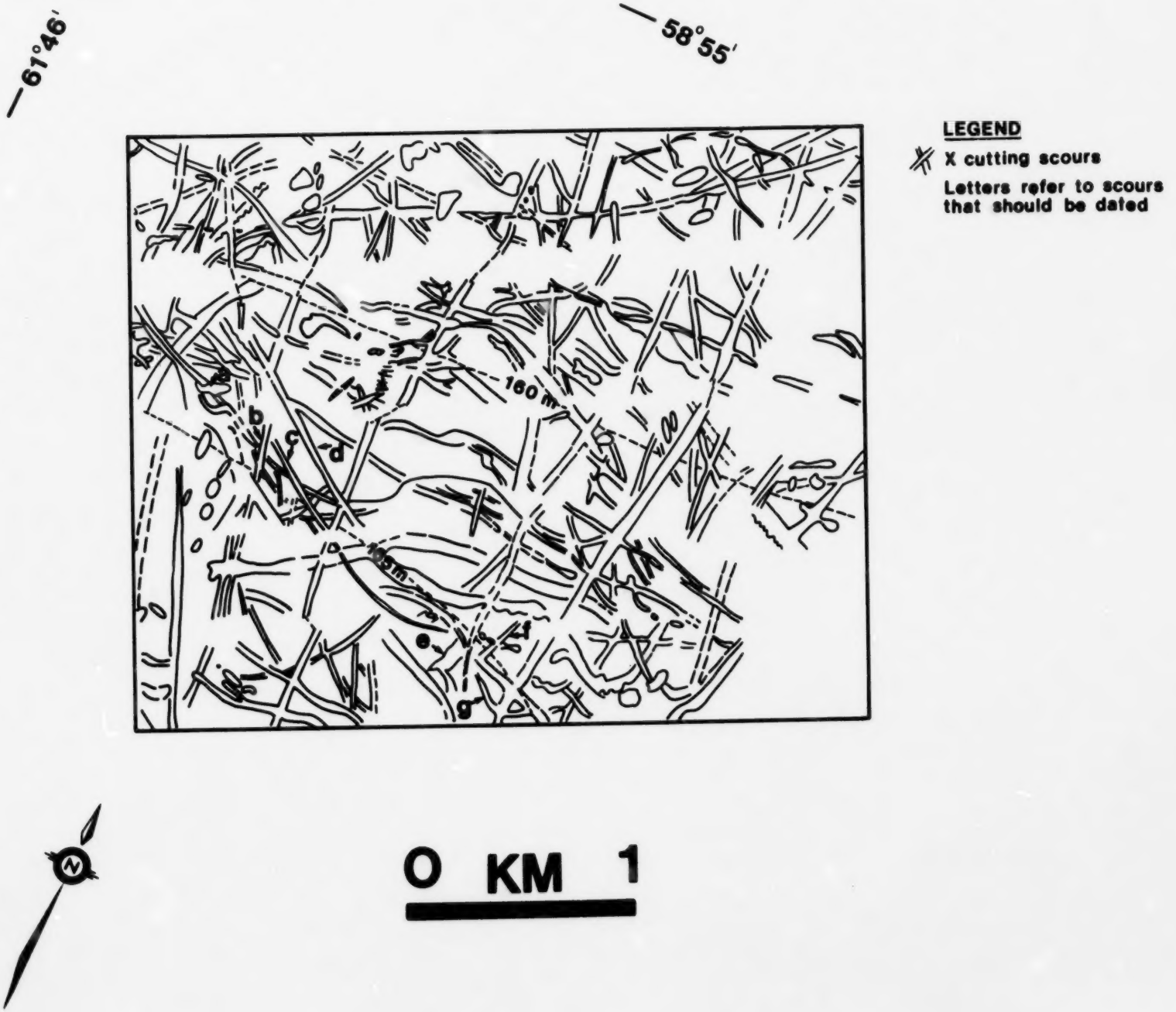
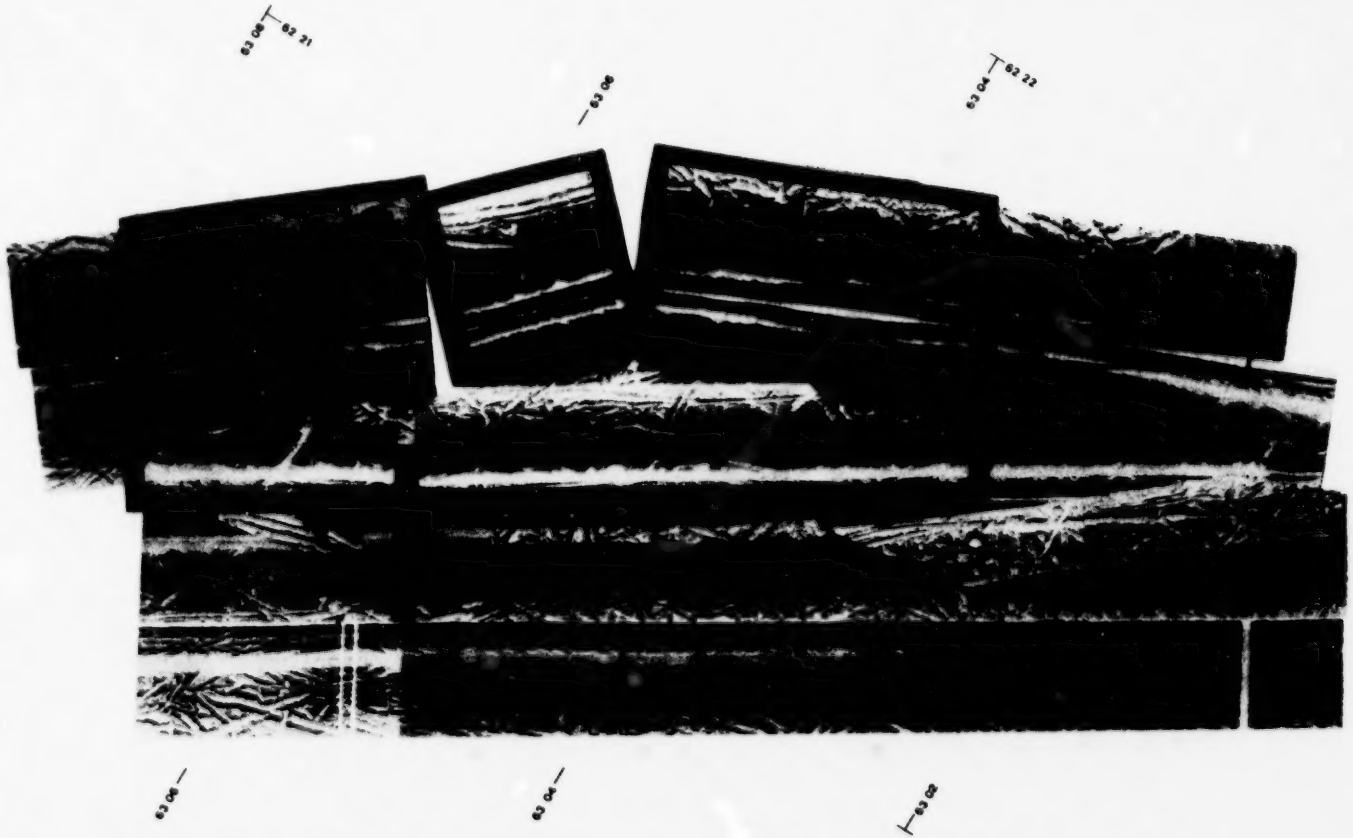

61°46'
58°55'
160 m
165m
b
c
d
LEGEND
X cutting scours
Letters refer to scours that should be dated
N
0 KM 1

Figure 5a - Hekja North mosaic area showing iceberg scours. The black outline shows the area of enlargement in figure 5b.



HEKJA NORTH MOSAIC

0 km 1

Figure 5b - Portion of Hekja North scour map (see Fig. 5a) showing the interpreted cross-cuts.

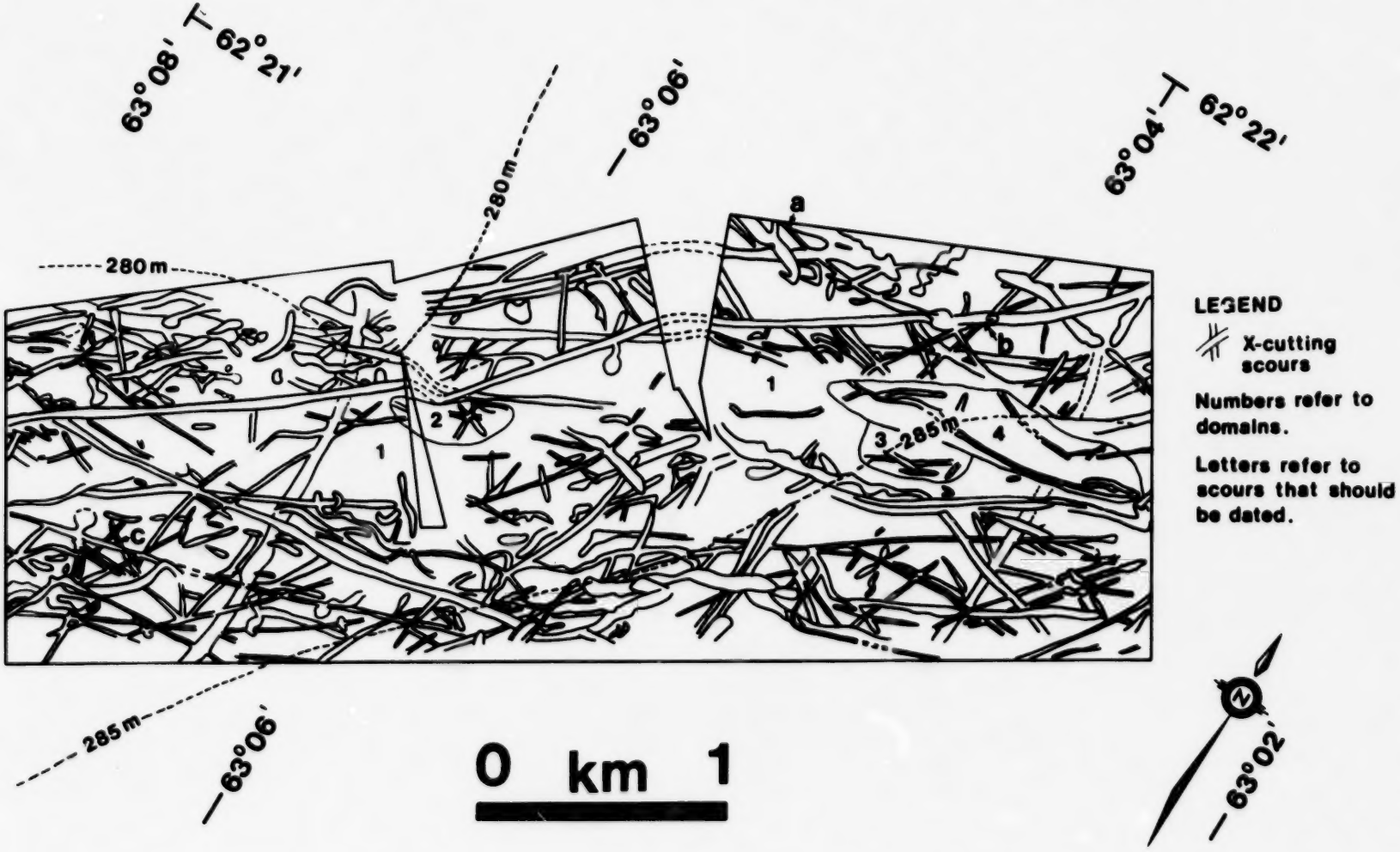

63°08'
62°21'
63°06'
63°04'
62°22'
280m
280m
285m
285m
63°06'
63°02'
a
b
c
1
2
3
4
Xc
0 km 1
LEGEND
X-cutting scours
Numbers refer to domains.
Letters refer to scours that should be dated.

Figure 6 - Morphological criteria for determining cross-cutting relationships. Each diagram is accompanied by a photograph of an example of the type of cross-cut from original sonograms.

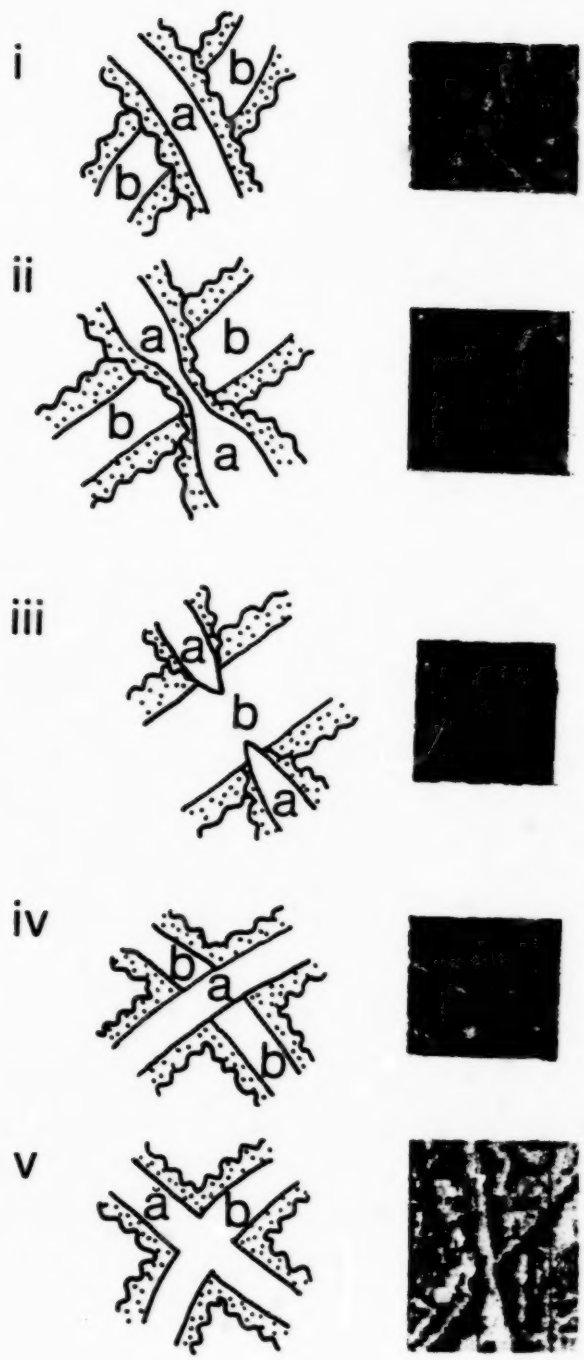
i) scour a. cuts scour b. Berm material of a. is thrown up into the trough of b.

ii) as in i, but scour a. has an hour glass shape indicating that scour b. has a pronounced trough.

iii) as in ii, but trough of b. is deeper than keel of berg that cross-cut scour b. so that only the berms of scour b. are cut.

iv) scour a. is deeper than scour b. but berm material is not present across either scour trough so cross-cut is not known.

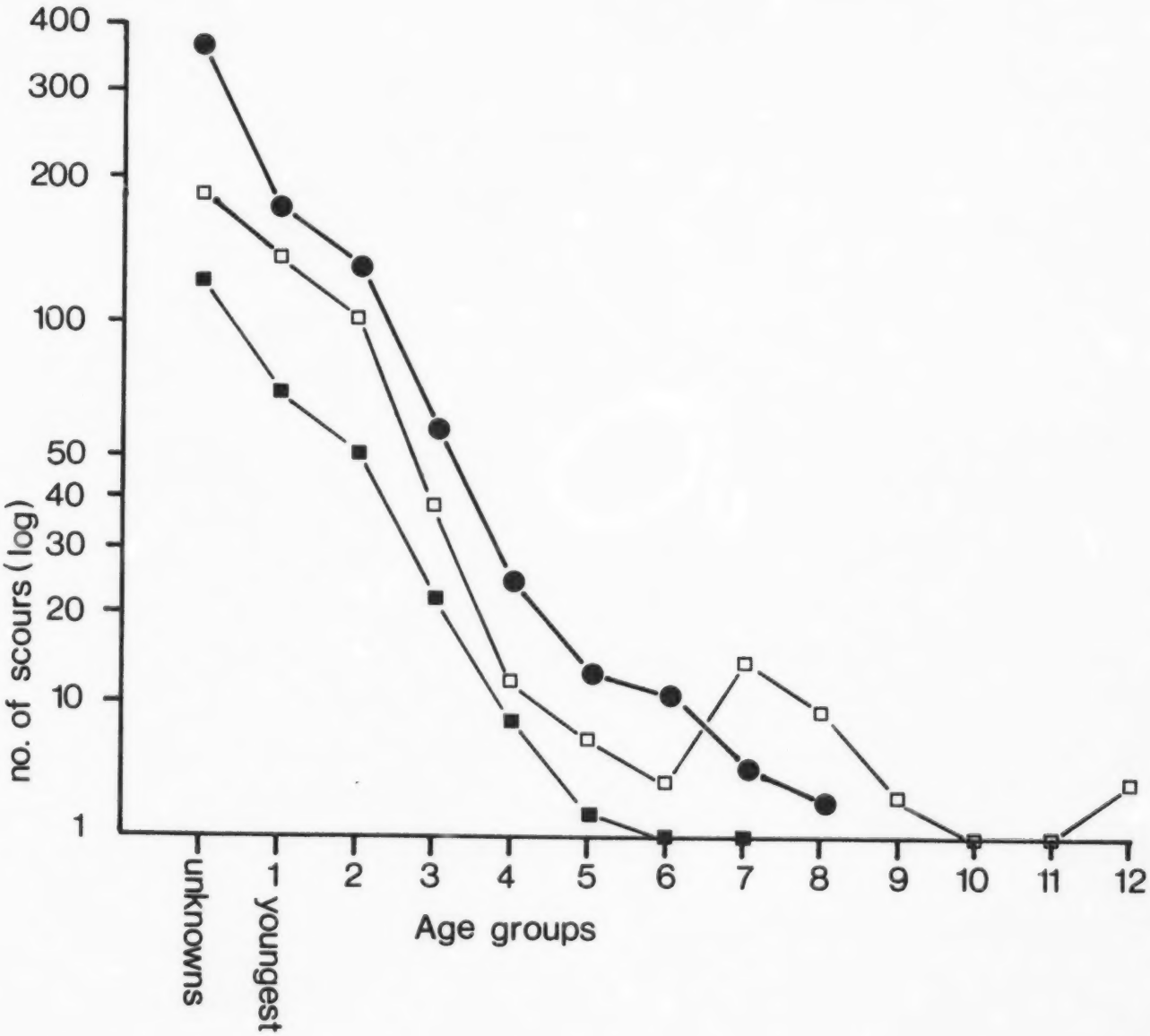
v) scours a. and b. are the same depth but absence of berm material in either trough means cross-cut is not known.


i
a
b
b
ii
a
b
b
a
iii
a
b
a
iv
b
a
b
v
a
b

Data Collection

Data from Saglek Bank were collected from the Canadian research vessel **CSS HUDSON** in August 1979 (Fillon, 1979) using the Bedford Institute of Oceanography 70 khz medium range side scan sonar system (Jollymore, 1974). Data from Hekja North were collected from **CSS HUDSON** in October 1981 (Lewis, 1982). The sidescan fish was towed behind the ship at heights from 60 - 80 m above the seabed. The slant range was set at 750 m, thus giving a total swath of approximately 1500 m. Sidescan data were recorded on board the ship on a Klein chemical wet paper recorder and on 1/4" magnetic tape. Time intervals every ten minutes were marked on both records and synchronized with the ship's navigation which automatically recorded location at one minute intervals. Navigation was accomplished utilizing Bionav, an integrated system of Loran C and satellite navigation. In the study areas the system is generally considered accurate to within about 200m. Subsequent to collection, sidescan data on the magnetic tapes were played back through a Honeywell model 1856A fibre optic visicorder onto heat sensitive dry silver paper to produce a positive image. This method of reproduction removed the distortions from the original sonograms and reduced the records to 1:10,000 scale. The strips were then assembled into mosaics at this scale. Scour features were matched between lines by small adjustments in the final position of the records. The assembled mosaics of the three study areas were photographed at the same 1:10,000 scale and from these scour maps were constructed and cross-cuts interpreted.

Figure 7 - Graph of scour age group vs. scour frequency


400
300
200
100
50
40
30
20
10
1
no. of scours (log)
unknowns
1
youngest
2
3
4
5
6
7
8
9
10
11
12
Age groups

Scour Age Groups

The number of scours in each age group fits an exponential distribution with more scours in the older age groups (Fig. 7). This is a function of fewer cross-cuts between older scours. If scouring began on an initially featureless seabed and if only one scour was generated at a time then it is unlikely that the first scours to be formed impinged on each other. Until cross-cutting of one scour by another (or others) occurs it is not possible to define the relative ages of the scours. It is possible, therefore, that some scours which should fall into younger age groups may not do so because of the lack of cross-cuts between early formed-scours. Figure 8 illustrates how this can arise. As the seabed becomes covered with scours, there is a progressively greater probability that newer scours will impinge on one or more of the older scours. As a consequence, while several scours may have the same relative age, thereby forming a relative age group, it is unlikely that all the scours in one age group are of the same absolute age. Thus with increasing scour cover it is possible to distinguish progressively smaller groups of relatively younger scours with increasing accuracy. It is likely therefore that the younger groups span a much shorter period of absolute time than do older groups.

Scour Cross-Cutting Domains

A scour domain is an area in which scours have known relative ages with respect to other scours in the domain. Relative age groups between domains cannot be correlated because scours in one

domain do not cross-cut scours in other domains. Several scour cross-cutting domains (Fig. 8 i - vii) are identified from the Saglek East and West and Hekja North scour maps. Domain boundaries are shown in Figure 5; Figures 3 and 4 are enlargements from within one domain.

Because interdomainal correlation is at present not possible on the basis of cross-cutting, only one domain from each of the three study areas has been chosen for analysis. The domains chosen are those which contain the greatest number of scours and in which all age groups are represented.

Scour Width

The width of each scour in the three scour domains was measured directly from the sonogram mosaics. Scour width approximates the distance between the two berm crests of a scour and is the size measurement used by researchers at the Atlantic Geoscience Centre (d'Appollonia and Lewis, 1981). The mean scour width when plotted against age group showed no significant correlation. However, when the three widest scours from each group were plotted against relative age, it was clearly shown that maximum scour width increased with increasing age (Fig. 9, 10, and 11). Some of the younger age groups in the study areas had fewer than three scours in total. In these cases all scours in the group were plotted.

The relationship between increasing scour width and increasing age was treated statistically to test the probability of finding scours of the same maximum width in all age groups.

Figure 8 - Diagram to illustrate the cross-cutting principle.

i) the relative ages of scours a. and b. cannot be determined because they do not cross-cut.

ii) scours a. and b. now fall into the earliest age group (group 1) because they are cut by scour c. which falls into the next youngest age group (group 2).

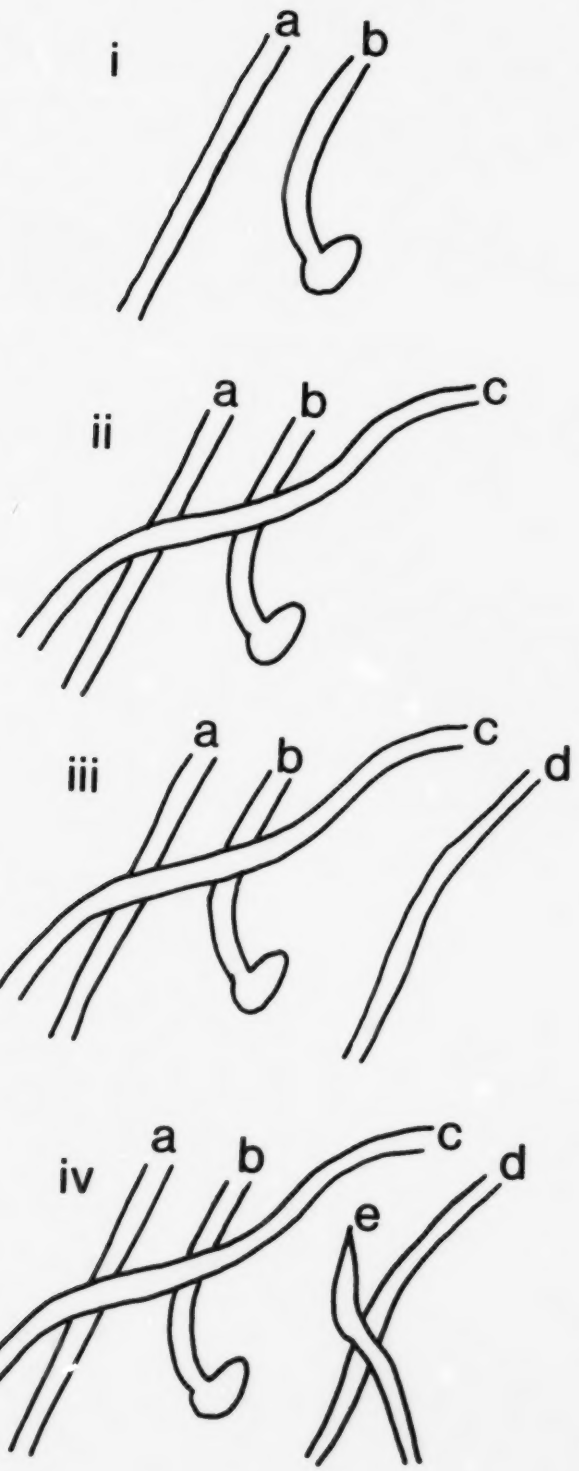
iii) scour d., though generated after scour c., cannot be assigned a relative age because it has no cross-cuts with the other scours.

iv) scours a., b. and d. now fall into group 1 even though scour d. is younger, in absolute terms, than scour c. Scours c. and e. now fall into age group 2.

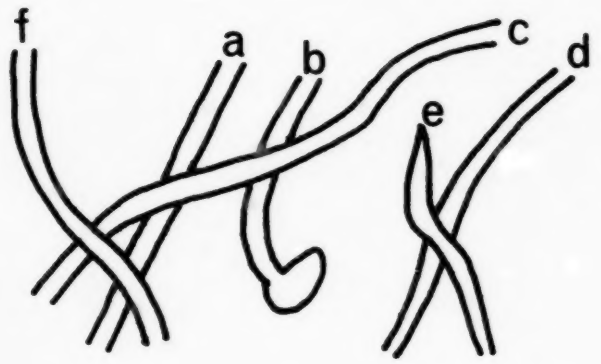
v) scour f. cuts a group 2 scour (scour c.) and thus falls into age group 3

vi) scour g., like f., cuts a group 2 scour (scour e.) and thus falls into age group 3 even though, in absolute terms, it is younger than scour f.

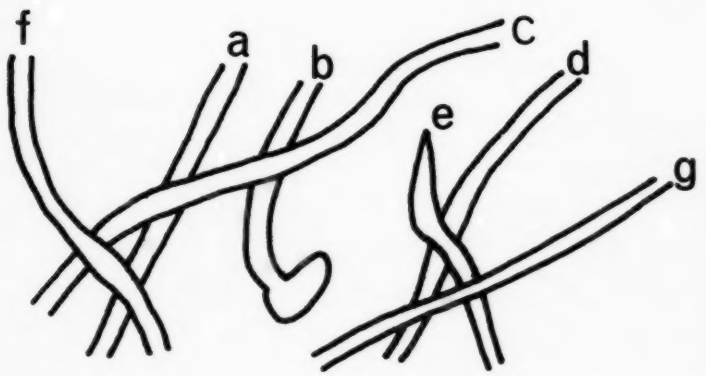
vii) scour h., though younger than scours f. and g. still falls into age group 3 because it cuts a group 2 scour (scour c.). Similarly, scour i. though also younger than scours f. and g., because it only cuts a group 1 scour (scour d.) falls into age group 2. The dotted line is a domain boundary separating the two populations of scours.


i
a
b
ii
a
b
c
iii
a
b
c
d
iv
a
b
c
d
e

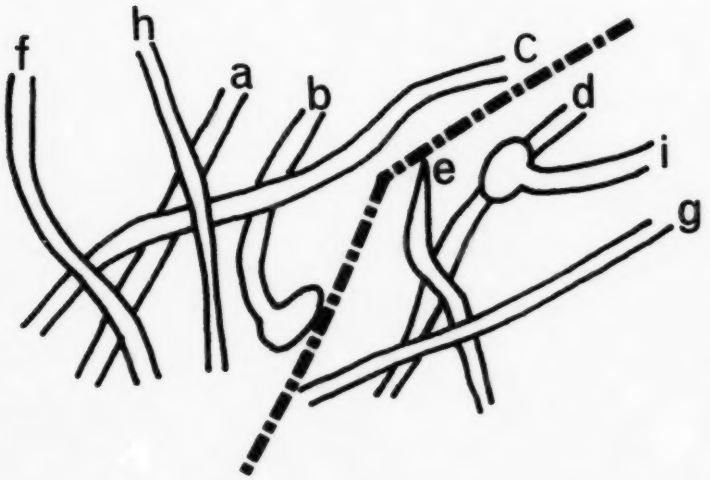
v



vi



vii



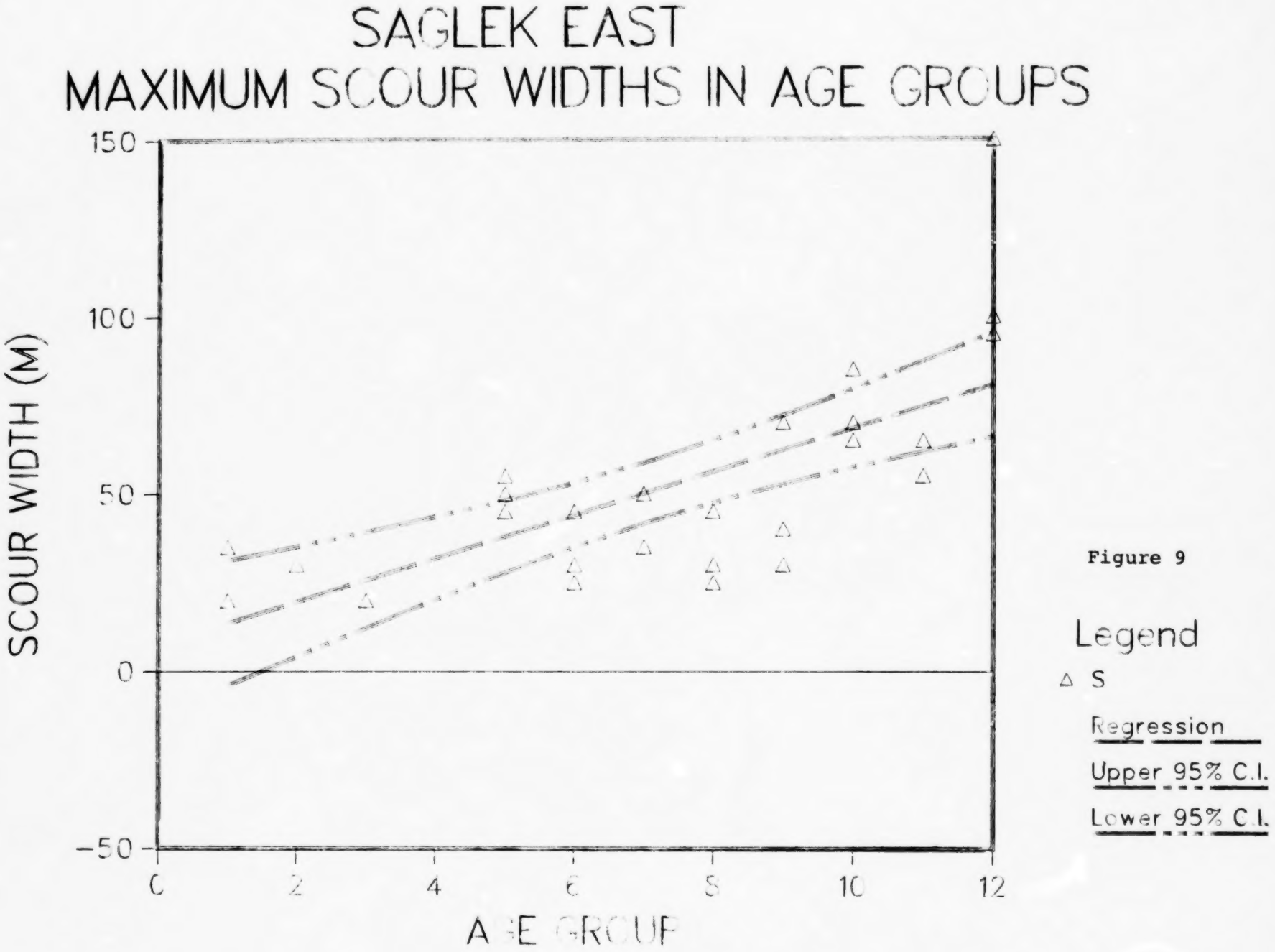

SAGLEK EAST
MAXIMUM SCOUR WIDTHS IN AGE GROUPS
SCOUR WIDTH (M)
150
100
50
0
-50
0
2
4
6
8
10
12
AGE GROUP
Legend
S
Regression
Upper 95% C.I.
Lower 95% C.I.

Figure 9

SAGLEK WEST
MAXIMUM SCOUR WIDTHS IN AGE GROUPS

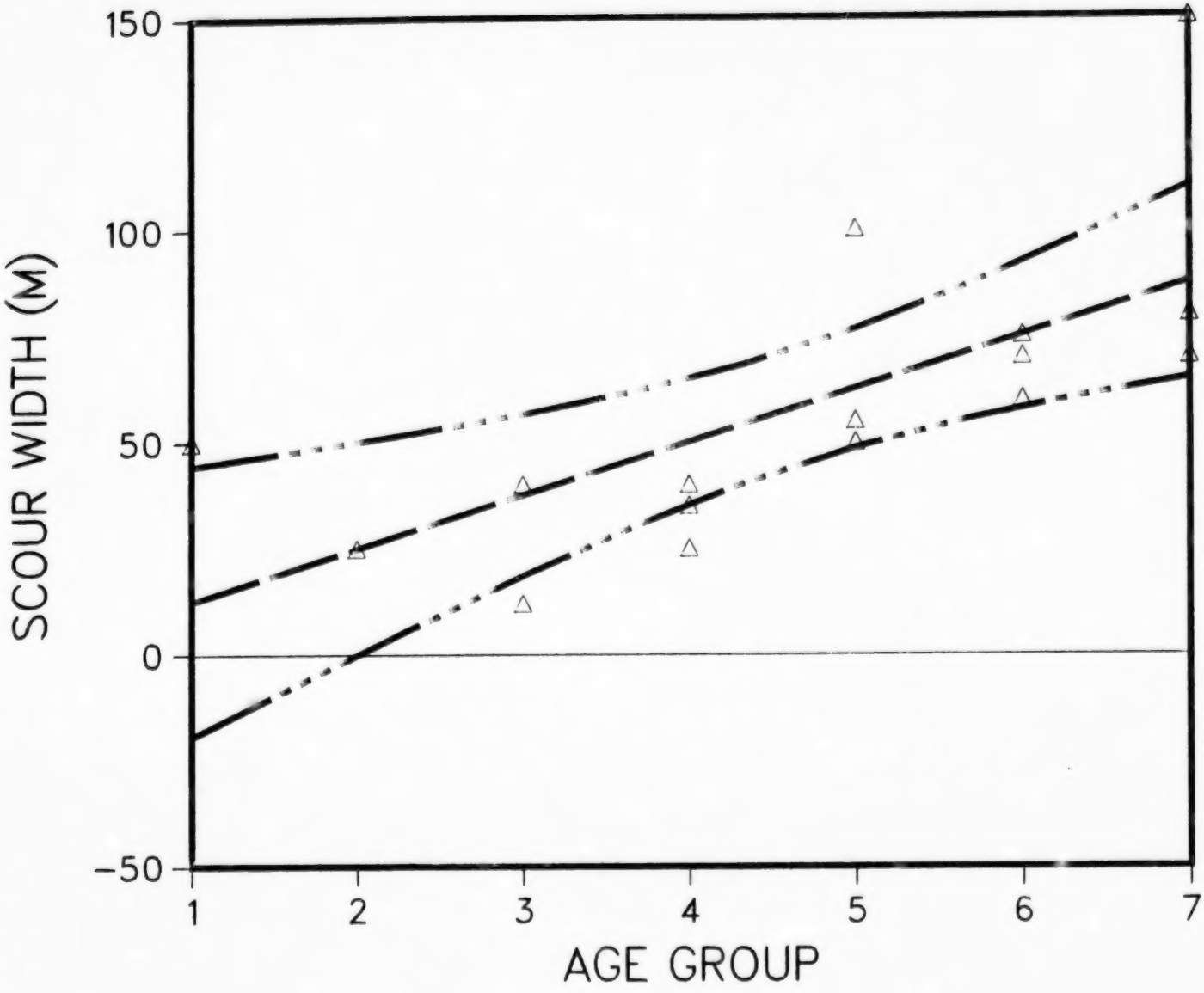


Figure 10

Legend

△ S

Regression

Upper 95% C.I.

Lower 95% C.I.

HEKJA NORTH
MAXIMUM SCOUR WIDTHS IN AGE GROUPS

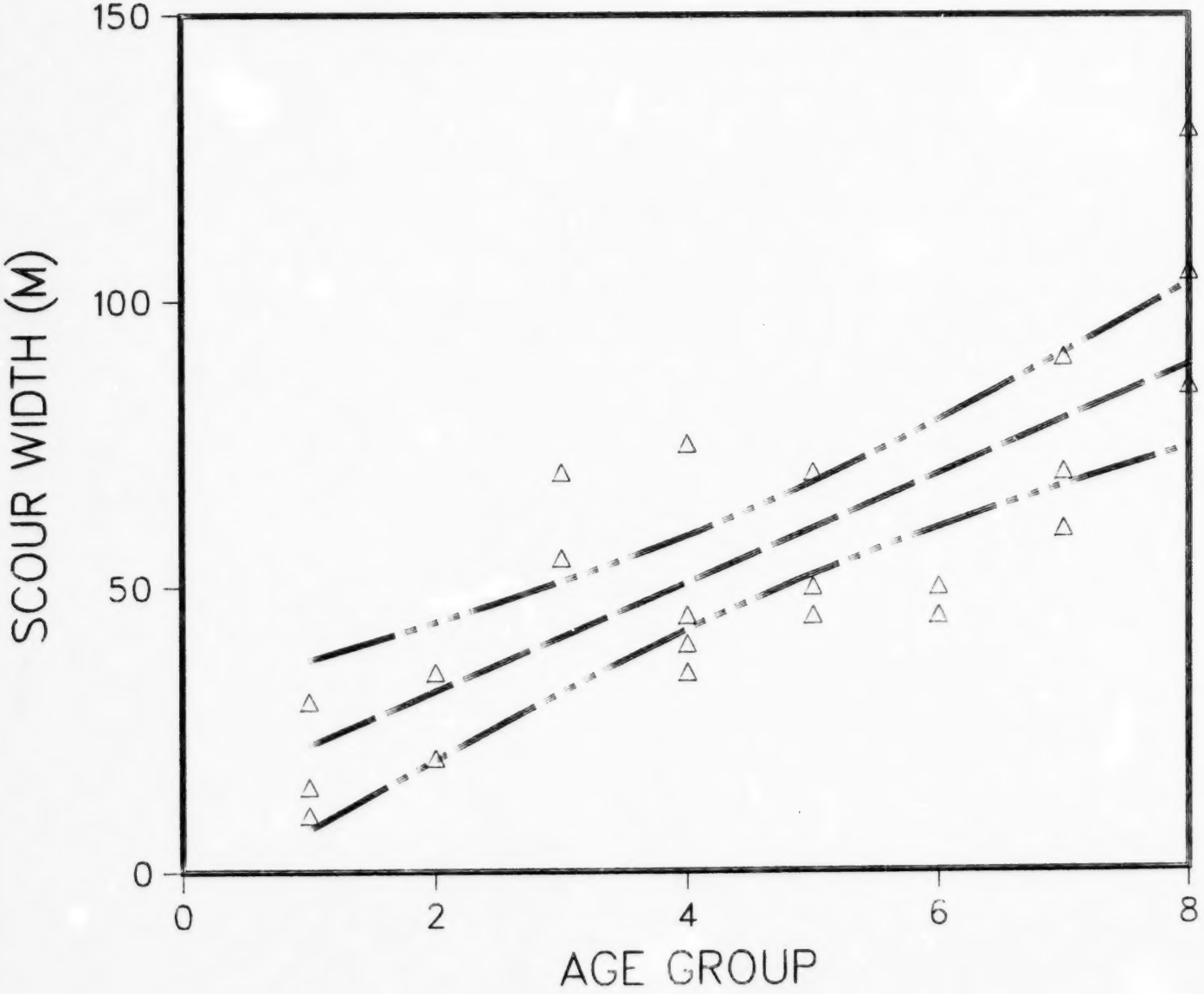


Figure 11

Legend

△ S

Regression

Upper 95% C.I.

Lower 95% C.I.

Unfortunately, the number of scours in the age groups above group 4 in all areas was too small to enable meaningful probability extrapolation and thus a statistically significant relationship could not be shown. This data deficiency can be remedied in future work if larger mosaic areas are analysed. This should result in the identification of larger domains and more age groups with scour frequency distributions similar to those in Figure 7. In particular, there should be more scours in older age groups to show a definite relationship between increasing scour width and increasing scour age.

RESULTS AND DISCUSSION

The results of the cross-cutting analysis for Saglek East and West and Hekja North are summarized in Table 1.

Oldest and Youngest Scours

The oldest scour group (group 1 in all study areas) contains the most scours and each scour has an unknown absolute age with respect to all scours in the group (refer to scour age groups section above). The oldest scours in a domain are identified by tracing all cross-cuts from the youngest scour group back through scours of progressively older groups until the oldest (group 1) scours are found. In this way two or more end member (oldest and youngest) scours are distinguished (Table 2).

TABLE 1

NUMBER OF CROSS-CUTTING SCOURS IN EACH AREA

	Saglek West	Saglek East	Hekja North
Total number of scours	236	532	774
Scours with unknown cross-cuts	95 (40.7%)	122 (22.9%)	362 (46.8%)
Scours with known cross-cuts	141 (59.3%)	410 (77.1%)	412 (53.2%)
Number of age groups	7	12	8
Number of cross-cut domains	14	5	10

TABLE 2

SELECTED 'END MEMBER' SCOURS IN EACH AREA

	Saglek West	Saglek East	Hekja North
Oldest scour age group	1	1	1
Number of end member scours in oldest group	4	2	1
Youngest scour age group	7	12	8
Number of end member scours in youngest group	1	4	2
Total scours defined and required for radiometric dating	5	6	3

Absolute Dating of End Member Scours

If radiometrically datable material can be cored from the troughs of the end member scours then three things are possible:

i) The minimum absolute age can be established for the oldest scour group (group 1). The age must be regarded as an approximate minimum value because it is possible that other scours in this age group are both younger and older than the dated end member scour(s).

ii) The age of the youngest scour group can be established. This age must also be regarded as an approximate minimum value because it is possible that young scours in other domains are both younger and older than the dated end member scour(s).

iii) An approximate scouring rate value between the two dates can be derived by dividing the number of scours in the domain into the time span.

The cross-cutting method greatly reduces the number of individual scours in a scour population that are required for sampling in order to define the time span over which scouring has occurred and for establishing a scouring rate.

Scour Age and Width Correlation

The decrease in maximum scour width in young age groups suggests that the bergs which produced these scours have decreased in size since scouring began. It may be argued that the decrease in maximum iceberg size correlates with retreat of calving ice margins during deglacial times. It might be expected that if iceberg sources were nearby to the scour study areas as scouring

began, then large icebergs capable of ploughing wide scours could have been introduced. As the calving margins retreated and icebergs had further to travel, the effects of melting, sublimation and calving would reduce the maximum size of bergs reaching the scour areas and the maximum widths of scours these bergs could generate.

CONCLUSIONS

Using iceberg scour cross-cutting relationships it is possible to define the relative ages of scour populations. A small number of end member scours can be selected for sampling and radiometric age dating. This would make the sampling of numerous scours unnecessary. The cross-cutting method has also led to the identification of a possible correlation between increasing scour width and increasing age which may yield information on the relative timing of retreat of the calving margins of ice sheets.

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